Indian Journal of Agronomy **69** (4): 397–403 (December 2024)
DOI: 10.59797/ija.v69i4.5542

Research Paper

Effect of pre- and post-emergence herbicides on weeds, productivity and profitability of maize

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Received: February 2024; Revised accepted: November 2024

ABSTRACT

A field experiment was conducted to find out the best combinations of pre- and post-emergence herbicides in maize for effective weed control and higher productivity at ICAR-Indian Institute of Maize Research, Ludhiana in 2021 and 2022. Results indicated that pre (PE)- and post-emergence (PoE) herbicide application, reduced the narrow-leaved weeds (NLW) and broad-leaved weeds (BLW) density from 62.41–91.46% and 55.53–82.11% respectively, compared to the weedy check. Among the PE, pyroxasulfone performed better than atrazine owing to selectivity towards maize with better weed control during both years. The density of *Cyperus spp*. was significantly reduced with halosulfuron PoE along with atrazine or pyroxasulfone PE over the years. A higher weed control efficiency (WCE) was found with pyroxasulfone followed by *(fb)* topramezone (90.4), while pyroxasulfone *fb* tembotrione (84.1) and atrazine *fb* topramezone (84.8) had similar WCE. Pyroxasulfone *fb* topramezone gave a 46.97% increase in grain yield over a weedy check. Pyroxasulfone *fb* topramezone and pyroxasulfone *fb* tembotrione resulted in higher net returns and B:C. Therefore, the application of pyroxasulfone as PE *fb* tembotrione as PoE or pyroxasulfone as PE *fb* topramezone as PoE may be recommended for better weed control and higher maize grain yield in NWPZ of India.

Key words: Broad-leaved weeds, Narrow-leaved weeds, Productivity, Yield reduction, Weed control efficiency

Maize (*Zea mays* L.) is India's third most important crop after rice and wheat occupying 9.6 Mha area with an average productivity of 3.0 tonnes/ha compared to the world average of 5.8/ha (FAO, 2023). In India, maize is primarily cultivated during the *kharif* season where weeds are the most important yield-limiting factor. In the rainy season, maize is infested by a wide range of weed flora, viz. *Panicum* spp., *Echinochloa colona*, *Cyperus rotundus*, *Commelina benghalensis* and *Trianthema portulacastrum* during initial crop growth stages, whereas *Dactyloctenium aegyptium* and *Parthenium* spp. toward the end of crop maturity. The critical period for crop weeds competition in maize is the first six weeks owing to initial slow growth and wider row spacing. In addition, continuous rainfall hinders manual weeding, therefore favoured weed growth which may reduce maize yield by 28–100% (Sharma *et al.,* 2018). Mostly, weeds are often managed through manual hoeing which has become uneconomical due to the escalating price of wadges nowadays. In addition, weeding by manual and mechanical means is not possible due to continuous rains in the monsoon season (Sepat *et al*., 2017). In maize, the most prevalent pre-emergence herbicide is atrazine used by farmers for weed control. However, several reports indicated that atrazine has developed resistance in certain weeds *Sonchus oleraceus*, *Sisymbrium orientale* and *Rapistvum rugosum* in several countries (Adkins *et al.*, 2008). Under such circumstances, there is an urgent need to explore other alternatives to these herbicides through the availability of new pre-emergence herbicides such as pyaroxasulfone and other post-emergence *viz.*, topramezone and tembotrione. Here, topramezone and tembotrione are selective, post-emergence herbicides that have been recently introduced for use in maize (Zhao *et al*., 2017). Both are pyrazolone herbicide that inhibits 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) and the biosynthesis of plastoquinone with subsequent carotenoid pigment formation, membrane structure and chlorophyll disruption in weeds (Zhao *et al*., 2017). As the critical period of crop-weed competition extends up to 50 days these provide an easy option for herbicidal-based weed management in maize, especially in later seasons. Addition-

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ally, in the scenario of no pre-emergence weed management, farmers can have options of suitable post-emergence herbicides for saving their crop from weed losses. Application of tembotrione at 125 and 150 g/ha at 20 DAS effectively reduced the dry weight of *Echinochloa colona*, *Commelina benghalensis*, *Polygonum alatum*, *Ageratum Conyzoides*, and produced higher grain yield of maize at Palampur (Rana *et al*., 2017). Tank mix application of tembotrione at 120 g/ha and topramezone at 25.2 g/ha as early post-emergence at 15 DAS or as a sequential application at 25 DAS with atrazine at 750 g/ha resulted in significantly high weed control and enhanced the yield of the maize (Chhokar *et al*., 2019). Tembotrione application in maize reduced the rhizomatous *Sorghum halepense* by 60-82% in Northern Greece. In addition, narrow-leaved weeds (NLWs), viz., *Echinochloa crus-galli*, and *Setaria viridis* were decreased by 90% without affecting the grain yield of maize (Su *et al*., 2020). However, the lowest weed index in maize was observed in the sequential application of tembotrione/topramezone at 25 DAS while the highest weed index (49.3) with sole halosulfuron *fb* atrazine application.. It has been observed that recently developed herbicides need to be tested at various combinations to find out the consolidated impact on maize productivity. Therefore, an experiment was initiated to identify suitable pre- and post-emergence herbicide combinations to enhance yield and profitability with less drudgery in maize production during 2021 and 2022 at ICAR-Indian Institute of Maize Research, Ludhiana, Punjab.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Research farm of ICAR-Indian Institute of Maize Research, Ladhowal, Ludhiana (30.59° N and 75.44° E and 247 msl) in *kharif* maize during 2021 and 2022. The climate of the site is semi-arid tropical having maximum and minimum temperature ranges from 45–22 °C. The average rainfall during the growing season (June to October) was 418 mm and 529 mm in 2021 and 2022, respectively. The soil was sandy loam in texture with pH of 8.3 and having 150 kg/ha, 11 kg/ha and 280 kg/ha available N, P and K, respectively.

Treatment detail

The experiment was conducted in randomized block design with 3 réplications having twelve sets of various pre and post-emergence herbicides combinations, viz. unweeded control (T_1), weedy check (T_2), atrazine 1.0 kg/ha + hand weeding at 25–30 DAS (T_3), pyroxasulfone 0.127 kg/ha *fb* hand weeding at 25–30 DAS (T_4), atrazine 1.0 kg/ha *fb* halosulfuron methyl 0.067 kg/ha (T_5), atrazine 1.0 kg/ha *fb* tembotrione 0.12 kg/ha (T_6), atrazine 1.0 kg/ha fb topramezone 0.025 kg/ha (T_7), atrazine 1.0 kg/ha *fb* mesotrione + atrazine 1.0 kg/ha (T_8), pyroxasulfone 0.127 kg/ha *fb* halosulfuron methyl 0.067 kg/ha (T_9), pyroxasulfone 0.127 kg/ha *fb* tembotrione 0.12 kg/ha (T_{10}), pyroxasulfone 0.127 kg/ha *fb* topramezone 0.025 kg/ha (T_{11}) and pyroxasulfone 0.127 kg/ha *fb* ready mix mixture of mesotrione + atrazine 1.0 kg/ha (T_{12}). Before sowing, seed treatment was done with imidacloprid 70 WS @ 10 g/kg of seed to protect the crop from stem borer incidence. Maize variety CPC 858 was taken, and sown during the second fortnight of June. The crop was sown on the ridge with a distance of 67.5 cm of row × row and 20 cm of plant × plant using 20 kg/ha seed. Irrigation was applied as per the crop requirement. The recommended dose of 180 kg N, 60 kg P_2O_5 and 40 kg K_2O through urea, di-ammonium phosphate and muriate of potash, respectively was applied in maize. A full amount P_2O_5 and K_2O was applied at sowing time while N was given in three equal splits at sowing, knee height (35 DAS) and tasseling stage (55 DAS). Fall armyworm incidence was controlled by a spray of chlorantraniliprole 18.5 SC at 15 and 25 DAS. The crop was harvested during the second fortnight of September in both years.

Statistical analyses

Data about yield attributes, viz. cob length, kernel rows/cob, kernels/row and prolificacy were recorded after harvest. The grain yield was recorded at 14% grain moisture content and expressed as t/ha. Weed control efficiency (%) was calculated by using the formulae (Das 2018):

$$\frac{\text{Weed density (no./m}^2\text{) in weedy check – Weed density(no./m}^2\text{) in treatment Weed density (no./m}^2\text{)}}{\text{Weed density (no./m}^2\text{) in unweeded control weedy check}}$$

Weed index (%) was calculated by using the formula: maize yield (kg/ha) in weed-free control - maize yield (kg/ha) in treatment ×100 / maize yield in weed-free control (kg/ha). Analysis of variance was computed by using SAS version 9.4 software. For treatment mean comparison, the least significant difference values were obtained at a 95% confidence interval.

RESULTS AND DISCUSSION

Yield attributes

The yield parameters such as no. of grains/cob, cob weight and grain weight/cob were highest in weed-free check (WFC), while the lowest recorded in (WC) during 2021 and 2022 (Table 1). Pyroxasulfone followed by (*fb*) tembotrione and pyroxasulfone fb topramezone recorded similar values of grains/cob, cob weight and grain weight/cob. An increase of 5.44-11.66% was found for grains/cob, cob weight and grain weight/cob with pyroxasulfone-fb topramezone over to atrazine fb hand weeding. Less competition for nutrient acquisition with weeds gave optimum partitioning of dry matter accumulating from stem to grains in maize (Bana *et al., 2020*). Consequently, higher grain formation was found with herbicide treatments. On average, the imposition of pyroxasulfone as PE observed a 3–4% increase in yield parameters than atrazine *fb* hand weeding, irrespective of POE herbicide applications.

Grain yield, stover yield, and harvest index

Maize grain yield significantly varied (5.57 to 7.11) with pre- and post-emergence herbicide application in 2021 and 2022 (Table 2). In weed-free, the highest yield of grain was recorded (7.45 t/ha), while (3.77 t/ha) gave the lowest one. Among the herbicides, pyroxasulfone *fb* topramezone and pyroxasulfone *fb* temobtrione recorded higher grain yields (6.97 and 7.11). Pyroxasulfone *fb* topramezone gave 46.97% higher grain yield over the T_1. The conventional practice of weed control through atrazine *fb* hand weeding observed a yield penalty of 18.84% compared to pyroxasulfone *fb* topramezone. Hand weeding at 35 days after sowing is considered the best practice for effective weed control with additional benefits of soil aeration to maize roots for better growth and nutrient acquisitions (Dass *et al*., 2017). However, irrespective of herbicides, we noticed that hand weeding recorded higher infestation of *Cyprus* spp. after 10 days of hand weeding. At 35 DAS, in maize, all categories of weeds such as broad-leaved, narrow-leaved, and sedges were heaved and cut by action of manual hand hoeing. But, ten days later, the intensity of sedges was high. It is well known that sedges spread by rhizomes and disruption of cut-down action by hand hoeing promoted increased growth of below-ground rhizomes which competed with maize for nutrient, water and space acquisitions (Rana *et al*., 2017). Application of mesotrione + atrazine recorded at par grain yield with pyroxasulfone *fb* tembotrione. The effective weed control of broad-leaved and slight reduction in the intensity of narrow-leaved such as *E. colonum* and *D. ageypticum* with pyroxasulfone followed by mesotrione + atrazine as PoE gave similar grain yield with pyroxasulfone *fb* tembotrione.

A more or less similar trend was found in the case of stover yield with herbicide applications. Application of herbicides in maize increased the stover yield ranges from 42.4–73.68%. Pyroxasulfone *fb* halosulfuron and pyroxasulfone *fb* tembotrione recorded at par stover yield of maize owing to a lesser infestation of weeds in maize. It is interesting to note that atrazine *fb* hand weeding recorded a 43.15% increase in stover yield over to T_1. On the other hand, ineffective weed management with hand

Table 1. Effect of pre-and post-emergence herbicides application on yield attributes of maize during 2021 and 2022

Treatment	No. of grains/cob		Cob weight (g/cob)		Grain weight/cob (g)	
	2021	2022	2021	2022	2021	2022
T_1	385	379	127	130	137	135
T_2	510	499	159	162	159	154
T_3	450	448	140	143	149	145
T_4	461	456	143	148	152	147
T_5	472	459	147	154	154	149
T_6	480	462	150	158	156	150
T_7	487	469	150	160	157	151
T_8	478	460	148	155	155	149
T9	484	467	150	156	155	150
T_{10}	496	482	154	160	157	152
T_{11}	500	489	155	161	158	152
T_{12}	492	472	149	158	156	149
SEm±	2.74	2.47	1.09	0.88	0.31	0.34
CD (P=0.05)	8.76	7.89	3.50	2.80	1.02	1.10

T_1, unweeded control; T_2, weedy check; T_3, atrazine + HW; T_4, pyroxasulfone *fb* HW; T_5, atrazine *fb* halosulfuron methyl; T_6, atrazine *fb* tembotrione; T_7, atrazine *fb* topramezone; T_8, atrazine *fb* mesotrione + atrazine; T_9, pyroxasulfone *fb* halosulfuron methyl; T_{10}, pyroxasulfone *fb* tembotrione; T_{11}, pyroxasulfone *fb* topramezone; T_{12}, pyroxasulfone *fb* mesotrione + atrazine

Table 2. Effect of pre- and post-emergence herbicides application on yields and harvest index of maize during 2021 and 2022.

Treatment	Grain yield (t/ha)		Stover yield (t/ha)		Harvest index (%)	
	2021	2022	2021	2022	2021	2022
T_1	4.07	3.47	4.87	4.63	45.7	42.7
T_2	7.12	7.77	8.00	8.93	47.1	46.5
T_3	5.63	5.90	6.53	7.10	46.3	45.4
T_4	5.98	6.03	7.07	7.20	45.8	45.6
T_5	5.47	6.13	6.57	7.33	45.4	45.5
T_6	6.00	6.70	7.13	7.87	45.7	46.0
T_7	6.25	6.85	7.37	8.10	45.9	45.8
T_8	5.87	6.41	7.00	7.57	45.6	45.9
T9	6.07	6.27	7.27	7.47	45.5	45.6
T_{10}	6.97	6.96	8.27	8.17	45.7	46.0
T_{11}	7.05	7.17	8.13	8.37	46.4	46.2
T_{12}	6.76	6.67	7.97	7.80	45.9	46.1
SEm±	0.15	0.19	0.17	0.18	0.6	0.8
CD (P=0.05)	0.45	0.56	0.49	0.52	1.7	2.5

T_1, unweeded control; T_2, weedy check; T_3, atrazine + HW; T_4, pyroxasulfone *fb* HW; T_5, atrazine *fb* halosulfuron methyl; T_6, atrazine *fb* tembotrione; T_7, atrazine *fb* topramezone; T_8, atrazine *fb* mesotrione + atrazine; T_9, pyroxasulfone *fb* halosulfuron methyl; T_{10}, pyroxasulfone *fb* tembotrione; T_{11}, pyroxasulfone *fb* topramezone; T_{12}, pyroxasulfone *fb* mesotrione + atrazine

weeding along with atrazine recorded a yield penalty of 21.32% compared to pyroxasulfone + topramezone. Harvest index (HI) represents the transformation of grain yield in terms of total biomass (grain + stover) significantly influenced by herbicide treatments. HI in pyroxasulfone *fb* tembotrione and pyroxasulfone fb topramezone were similar to weed-free control (46–47). A reduction in harvest index was noticed with the T_1(43).

Economics

In the T_1, no control measures were taken, therefore, the low cost of cultivation (38.47) was recorded (Table 3). The lowest grain and stover yield in the T_1 and recorded the lowest net returns and B:C ratio (0.91). On the other hand, in weed-free control, to maintain the weed-free conditions, a total of 8–9 manual hand weeding was done which increased the cost of production. The yield of maize was higher in weed-free control. However, the high cost of cultivation decreased the net returns (–97.85 × 10^3/ha) and B:C ratio (1.95).

Similarly, atrazine *fb* hand weeding and pyroxasulfone *fb* hand weeding observed a high cost of cultivation among the pre and post-herbicide treatments. High wages in these treatments lowered the net returns and B:C. On the other hand, pyroxasulfone is a costly herbicide compared to atrazine. Therefore, in pyroxasulfone with various POE herbicide combinations, the cost of cultivation was increased by ₹ 1,000–2200/ha over to atrazine with POE combinations (Chhokar *et al*., 2019). However, the high grain and stover yield per rupee invested resulted in higher net returns and B:C ratios. Here, pyroxasulfone *fb* topramezone and pyroxasulfone *fb* tembotrione fetched higher net returns and B:C owing to effective weed control.

Weed density and biomass

Weed density was categorized into broad-leaved weed (BLW), narrow-leaved weed (NLW) and sedges during the study period. In BLW, *Trianthema portulacastrum* Linn., *Phyllanthus niruri* L. and *Amaranthus viridis* L. were the major weeds, while in NLWs, *Echinochloa colona* (L.) Link, *Digitaria ciliaris* (Retz.) Koeler and *Leptochloa chinensis* (L.) and *Cynodon dactylon* (L.) Pers. were present on a majority basis. In sedges, the dominant weed was *Cyperus rotundus* L. The sum of BLWs, NLWs and sedges was included in total weed density. The application of herbicides significantly influenced all categories of weed density during 2021 and 2022. On average, pre- and post-emergence herbicide application, reduced the NLW and BLW density by 62.4–91.5% and 55.5–82.1% compared to T_1 (Table 5). The application of topramezone or tembotrione with pyroxasulfone recorded the lowest NLW (11.5/m^2) and BLW (14.5/m^2) density compared to the standard practice of atrazine *fb* hand weeding (17.5 and 23.5/m^2). The lowest BLWs density was noticed with pyroxasulfone *fb* topramezone and

Table 3. Effect of pre-and post-emergence herbicides application on economics of maize during 2021 and 2022

Treatment	Cost of cultivation ($\times10^3$/ha)		Net returns ($\times10^3$/ha)		Benefit: cost ratio	
	2021	2022	2021	2022	2021	2022
T_1	40.0	45.0	35.29	41.64	0.88	0.93
T_2	48.0	53.0	83.65	114.05	1.74	2.15
T_3	47.1	52.1	57.07	80.63	1.21	1.55
T_4	51.0	56.0	59.56	78.64	1.17	1.40
T_5	42.9	47.9	58.15	89.15	1.35	1.86
T_6	41.6	46.6	69.36	100.46	1.67	2.15
T_7	41.9	46.9	73.68	104.53	1.76	2.23
T_8	40.7	45.7	67.79	95.75	1.66	2.09
T9	46.8	51.8	65.39	87.78	1.40	1.69
T_{10}	45.5	50.5	83.38	102.21	1.83	2.02
T_{11}	45.8	50.8	84.62	105.03	1.85	2.07
T_{12}	44.6	49.6	80.52	96.26	1.81	1.94
SEm±	-	-	28.42	33.40	0.06	0.07
CD (P=0.05)	-	-	83.35	97.98	0.19	0.20

T_1, unweeded control; T_2, weedy check; T_3, atrazine + HW; T_4, pyroxasulfone *fb* HW; T_5, atrazine *fb* halosulfuron methyl; T_6, atrazine *fb* tembotrione; T_7, atrazine *fb* topramezone; T_8, atrazine *fb* mesotrione + atrazine; T_9, pyroxasulfone *fb* halosulfuron methyl; T_{10}, pyroxasulfone *fb* tembotrione; T_{11}, pyroxasulfone *fb* topramezone; T_{12}, pyroxasulfone *fb* mesotrione + atrazine

Table 4. Effect of pre- and post-emergence herbicides application on weed density in maize during 2021 and 2022

Treatment	Narrow-leaved (no/m^2)		Broad-leaved (no/m^2)		Sedges (no/m^2)		Total (no/m^2)	
	2021	2022	2021	2022	2021	2022	2021	2022
T_1	11.77(138)	11.50(132)	8.92(79)	10.83(117)	8.69(75)	9.76(95)	17.10(292)	18.53(343)
T_2	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)
T_3	7.78(60)	7.78(60)	6.44(41)	6.36(40)	6.60(43)	7.78(60)	12.02(144)	12.67(160)
T_4	5.15(26)	6.52(42)	6.44(41)	5.79(33)	6.20(38)	7.52(56)	10.27(105)	11.47(131)
T_5	7.11(50)	7.20(51)	7.25(52)	5.96(35)	3.67(13)	3.67(13)	10.75(115)	9.99(99)
T_6	4.53(20)	4.95(24)	6.28(39)	5.34(28)	3.39(11)	3.39(11)	8.40(70)	7.97(63)
T_7	3.81(14)	4.15(17)	5.87(34)	5.15(26)	3.08(9)	3.08(9)	7.58(57)	7.22(52)
T_8	4.53(20)	4.25(18)	4.74(22)	4.95(24)	5.87(34)	7.11(50)	8.75(76)	9.60(92)
T9	5.96(35)	6.52(42)	6.20(38)	5.24(27)	2.74(7)	3.39(11)	8.97(80)	8.97(80)
T_{10}	4.18 (17)	3.54(12)	5.34(28)	4.42(19)	3.08(9)	2.74(7)	7.38(54)	6.20(38)
T_{11}	3.67(13)	3.24(10)	4.30(18)	4.18(17)	2.35(5)	2.12(4)	6.04(36)	5.61(31)
T_{12}	4.18(17)	3.67(13)	4.30(18)	5.15(26)	6.04(36)	2.92(8)	8.46(71)	6.89(47)
SEm±	2.25	2.23	2.29	2.24	2.02	1.67	3.49	3.42
CD (P=0.05)	3.72	3.68	3.80	3.70	3.31	2.68	5.90	5.78

T_1, unweeded control; T_2, weedy check; T_3, atrazine + HW; T_4, pyroxasulfone *fb* HW; T_5, atrazine *fb* halosulfuron methyl; T_6, atrazine *fb* tembotrione; T_7, atrazine *fb* topramezone; T_8, atrazine *fb* mesotrione + atrazine; T_9, pyroxasulfone *fb* halosulfuron methyl; T_{10}, pyroxasulfone *fb* tembotrione; T_{11}, pyroxasulfone *fb* topramezone; T_{12}, pyroxasulfone *fb* mesotrione + atrazine

pyroxasulfone *fb* tembortione. Pyroxasulfone belongs to isoxazoline group, a broad-spectrum herbicide, and was found very effective against grasses and BLWs. Therefore, the density of total weeds were reduced by 29.93% over atrazine, irrespective of PoE herbicides. Among the PE, pyroxasulfone performed better than atrazine owing to selectivity towards maize with better weed control during 2021 and 2022. In PoE, the density of *Cyperus spp*.

was significantly reduced with halosulfuron PoE along with atrazine or pyroxasulfone PE over the years. Halosulfuron (trade name: Sampra) has high knockdown effects on *Cyperus* spp. as it inactivates acetolactate synthesis, a key enzyme for metabolic pathways in weeds (Damalas *et al*., 2018).

The effects were apparent 15–20 days later if herbicide spray with visible yellowing of *Cyperus app*. vegetation and consequently mortality of underground rhizomes. The second-best treatment in POE was tembortione (trade name: Laudis) being herbicide that has a negative affinity towards BLW, NLW and sedges (Gitasopoulos *et al*., 2010). It acts by inhibiting the formation of carotenoid pigment synthesis, which gives a bleached appearance and stunted growth in weeds (Grossmann and Ehrhardt 2007). Overall, in controlling sedges, the following order was found: pyroxasulfone *fb* halosulfuron >pyroxasulfone *fb* tembotrione remained similar to atrazine *fb* halosulfuron. A low density of NLWs, BLWs and sedges led to a significant reduction in total weed density with pre-and post-emergence herbicide treatments. The total weed density ranges from 33.5 to 107.17/m^2. Hand weeding along with atrazine or pyroxasulfone recorded 152 and 118/m^2 weed density, respectively. The effective weed control with pre-and post-emergence herbicides gave a 52.3–90.55% reduction in total weed density compared to the T_1. Similarly, pre-and post-emergence herbicides recorded a 47.36–79.60% decrease in total weed density over hand weeding with PE application of herbicides.

A similar trend of weed density was noticed with different categories of weed biomass during 2021 and 2022 (Table 6). A reduction in NLWs density by 93.3 and 85.9 % was observed with pyroxasulfone *fb* topramezone and pyroxasulfone *fb* tembitrione, respectively over to T_1. In BLWs, a reduction of 28.7-66.08% was recorded with pyroxasulfone *fb* topramezone and pyroxasulfone *fb* tembitrione over conventional practice of atrazine *fb* hand weeding. A remarkable decrease (80.1%) in sedge biomass was noticed with atrazine *fb* halosulfuron and pyroxasulfone *fb* halosulfuron over to weedy check. Better control of NLWs and BLWs density through pyroxasulfone *fb* tembitrione was reflected in total weed biomass during 2021 and 2022. The total weed density was reduced by 90.55 and 76.70% with pyroxasulfone *fb* tembotrione compared to T_1 and atrazine *fb* hand weeding, respectively.

Weed Indices

Weed control efficiency (WCE) significantly influenced herbicide application in maize. WCE increased from 58.7–90.4% with impositions of herbicides in maize during 2021 and 2022 (Table 6). A higher WCE was found with pyroxasulfone *fb* topramezone (90.4), while pyroxasulfone fb tembotrione (84.1) and atrazine fb topramezone (84.8) were observed with similar values of

Table 5. Effect of pre-and post-emergence herbicides application on weed biomass of maize during 2021 and 2022

Treatment	Narrow-leaved (g/m^2)		Broad-leaved (g/m^2)		Sedges (g/m^2)		Total (g/m^2)	
	2021	2022	2021	2022	2021	2022	2021	2022
T_1	13.87(192)	15.98(255)	15.83(250)	16.99(288)	13.44(180)	13.87(192)	24.93(621)	27.10(734)
T_2	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)
T_3	9.67(93)	9.82(96)	7.78(60)	7.45(55)	10.98(120)	11.51(132)	16.54(273)	16.84(283)
T_4	8.92(79)	7.91(62)	7.91(62)	8.40(70)	10.79(116)	10.98(120)	16.05(257)	15.89(252)
T_5	9.35(87)	9.08(82)	8.97(80)	8.75(76)	7.11(50)	6.96(48)	14.75(217)	14.34(205)
T_6	6.67(44)	6.04(36)	7.04(49)	6.28(39)	6.75(45)	6.52(42)	11.77(138)	10.84(117)
T_7	6.04(36)	5.70(32)	5.70(32)	5.52(30)	6.20(38)	6.04(36)	10.32(106)	9.87(97)
T_8	6.28(39)	5.87(34)	6.20(38)	5.96(35)	9.08(82)	8.51(72)	12.63(159)	11.90(141)
T9	7.45(55)	6.96(48)	8.15(66)	8.51(72)	6.20(38)	6.04(36)	12.63(159)	12.51(156)
T_{10}	5.87(34)	5.43(29)	6.36(40)	6.52(42)	6.04(36)	5.70(32)	10.51(110)	10.17(103)
T_{11}	4.30(18)	3.54(12)	4.64(21)	4.30(18)	5.70(32)	5.34(28)	8.46(71)	7.58(57)
T_{12}	5.70(32)	5.34(28)	6.67(44)	6.82(46)	8.28(68)	8.40(70)	12.02(144)	12.02(144)
SEm±	2.07	1.41	2.08	1.80	1.81	1.29	2.74	2.35
CD (P=0.05)	3.40	2.20	3.32	2.92	2.94	1.98	4.59	3.91

T_1, unweeded control; T_2, weedy check; T_3, atrazine + HW; T_4, pyroxasulfone *fb* HW; T_5, atrazine *fb* halosulfuron methyl; T_6, atrazine *fb* tembotrione; T_7, atrazine *fb* topramezone; T_8, atrazine *fb* mesotrione + atrazine; T_9, pyroxasulfone *fb* halosulfuron methyl; T_{10}, pyroxasulfone *fb* tembotrione; T_{11}, pyroxasulfone *fb* topramezone; T_{12}, pyroxasulfone *fb* mesotrione + atrazine

Table 6. Effect of pre-and post-herbicide application on weed indices during 2021 and 2022

Treatment	Weed control efficiency (%)		Weed index (%)	
	2021	2022	2021	2022
T_1	-	-	42.8	55.5
T_2	100	100	-	-
T_3	56.0	61.4	20.8	24.0
T_4	58.5	65.6	16.0	22.3
T_5	65.1	72.1	23.2	21.0
T_6	77.7	84.1	15.7	13.8
T_7	82.9	86.8	12.2	11.9
T_8	74.4	80.9	17.5	17.5
T9	74.4	78.8	14.8	19.2
T_{10}	82.2	86.0	2.1	10.5
T_{11}	88.6	92.2	0.9	7.8
T_{12}	76.8	80.4	5.0	14.2
SEm±	0.99	0.61	2.17	2.52
CD (P=0.05)	2.92	1.78	6.36	7.38

T_1, unweeded control; T_2, weedy check; T_3, atrazine + HW ; T_4, pyroxasulfone *fb* HW ; T_5, atrazine *fb* halosulfuron methyl; T_6, atrazine *fb* tembotrione ; T_7, atrazine *fb* topramezone; T_8, atrazine *fb* mesotrione + atrazine ; T_9, pyroxasulfone *fb* halosulfuron methyl; T_{10}, pyroxasulfone *fb* tembotrione ; T_{11}, pyroxasulfone *fb* topramezone ; T_{12}, pyroxasulfone *fb* mesotrione + atrazine

WCE. In atrazine *fb* hand weeding and pyroxasulfone *fb* hand weeding, WCE ranges from 58.7–62.1%. With the imposition of pre-and post-emergence herbicides, an increase of 28–45% was found compared to atrazine *fb* hand weeding. The highest percent yield reduction (42.8% and 55.5% in 2021 and 2022, respectively) was noticed in the T_1 which means a higher weed index (WI). This indicates that weeds can cause yield losses in maize up to 55.5% without a suitable weed control strategy. The traditional practice of atrazine *fb* hand weeding causes the yield penalty by 20.8 to 24.0%. Whereas, with the imposition of pre- and post-emergence herbicide combinations only a 10–17% reduction in yield was noticed in maize.

Weed management in maize is imperative for higher productivity and profits with less drudgery work. Based on the study, it can be concluded that the imposition of herbicides is essential for higher productivity in maize. Application of pyroxasulfone as PE at 0.127 kg/ha followed by tembotrione as PoE at 0.12 kg/ha and pyroxasulfone as PE at 0.127 kg/ha followed by topramezone as PoE at 0.025 kg/ha enhances grain yield of maize with better control of weeds.

REFERENCES

Sepat, S., Phogat, B., Bana, R.S., Kumar, D. and Meena, S.L. 2023. Assessment or precise nutrient management through nutrient expert on productivity and profitability of zero-till maize. *Indian Journal of Agronomy* **68:** 379–385.

Hitesh, S., Sepat, S., Babu, S. and Das, T.K. 2018. Weed and nitrogen management effects on weed flora and productivity of transplanted rice (*Oryza sativa*) in North-Eastern region of India. *Indian Journal of Agronomy* **63**(4): 513–516.

Adkins, S.W., Wills, D., Boersma, M., Walker, S.R., Robinson, G., Mcleod, R.J. and Einam, J.P. 2008. Weeds resistant to chlorsulfuron and atrazine from the north-east grain region of Australia. *Weed Research* https://doi.org/10.1046/j.1365-3180.1997.d01-56.x.

Bana, R.S., Singh, D., Nain, M.S., Kumar, H., Kumar, V. and Sepat, S. 2020. Weed control and rice yield stability studies across diverse tillage and crop establishment systems under on-farm environments. *Soil and Tillage Research* **204**: 104,729.

Chhokar, R.S., Sharma, R.K., Gill, S.C. and Singh, R.K. 2019. Mesotrione and atrazine combination to control diverse weed flora in maize. *Indian Journal of Weed Science* **51**(2): 145–150.

Dass, A., Shekhawat, K., Choudhary, A.K., Sepat, S., Rathore, S.S., Mahajan, G. and Chauhan, B.S. 2017. Weed management in rice using crop competition-a review. *Crop Protection* **95**: 45–52.

Das, T.K. 2018. Using chemical seed dormancy breakers with herbicides for weed management in soybean and wheat. *Weed Research* **58:** 188–99.

FAO STAT. 2023. Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) online database.

Gitasopoulos, T.K., Melidis, V. and Evgenidis, G. 2010. Response of maize (*Zea mays* L.) to post-emergence applications of topramezone. *Crop Protection* **29**(10): 1,091–1,093.

Grossmann, K. and Ehrhardt, T. 2007. On the mechanism of action and selectivity of the corn herbicide topramezone: A new inhibitor of 4-hydroxyphenyl pyruvate dioxygenase. *Pest Management Science* **63**(5): 429–439.

Rana, S.S., Badiyala, D., Sharma, N., Rajinder, K. and Pathania, P. 2017. Impact of tembotrione on weed growth, yield and economics of maize (*Zea mays* L.) under mid hill conditions of Himachal Pradesh. *Pesticide Research Journal* **29 (**1): 27–34.

Sepat, S., Thierfelder, C., Sharma, A.R., Pavuluri, K., Kumar, D., Iquebal, M.A. and Verma, A. 2017. Effects of weed control strategy on weed dynamics, soybean productivity and profitability under conservation agriculture in India. *Field Crops Research* **210**: 61–70.

Sharma, P., Duary, B., and Singh, R. 2018. Tank mix application of tembotrione and atrazine to reduce weed growth and increase productivity of maize. *Indian Journal of Weed Science* **50**(3): 305–308.

Su, Y., Wang, W., Hu, J. and Liu, X. 2020. Dissipation behaviour, residues distribution and dietary risk assessment of tembotrione and its metabolite in maize via QuEChERS using HPLC-MS/MS technique. *Ecotoxicology and Environmental Safety* **191**: 110,187.

Zhao, F., Xiang, Q., Zhou, Y., Xu, X., Qiu, X., Yu, Y. and Ahmad, F. 2017. Evaluation of the toxicity of herbicide topramezone to *Chlorella vulgaris*: Oxidative stress, cell morphology and photosynthetic activity. *Ecotoxicology and Environmental Safety* **143**: 129–135.